Recent Progress in SRF Acceleration Technology at Peking University

Presenter: Senlin Huang

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Outline

- Stable Operation of DC-SRF Photoinjector
- Construction of Straight Section
- Summary and Outlook

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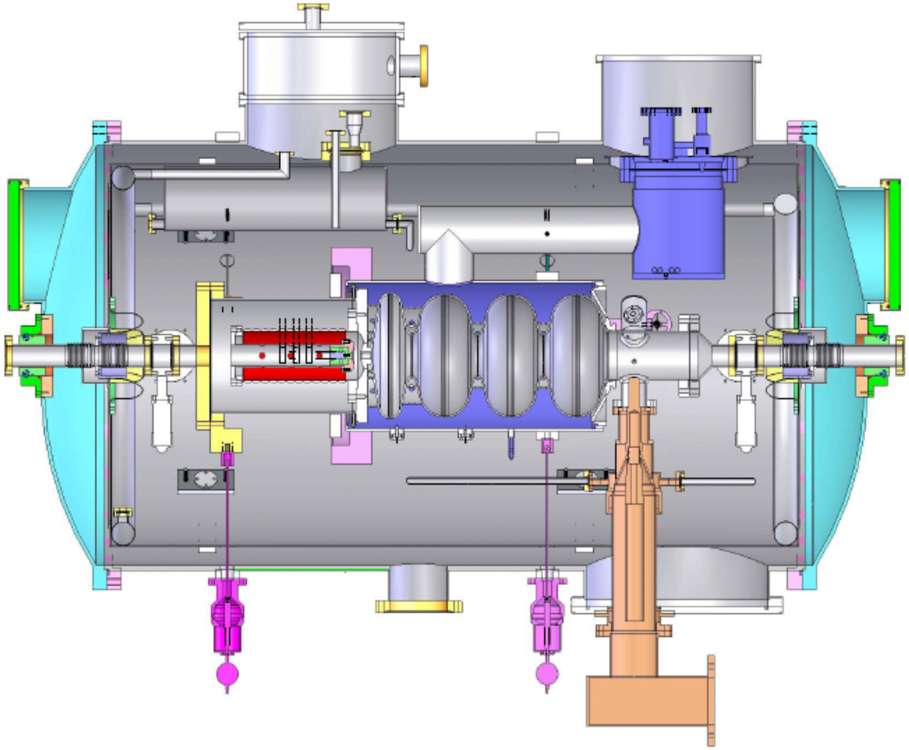
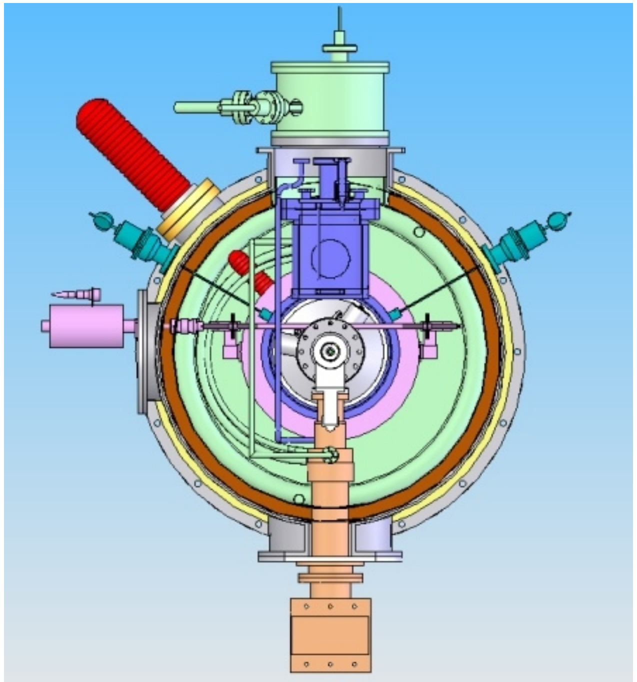
DC-SRF Photoinjector



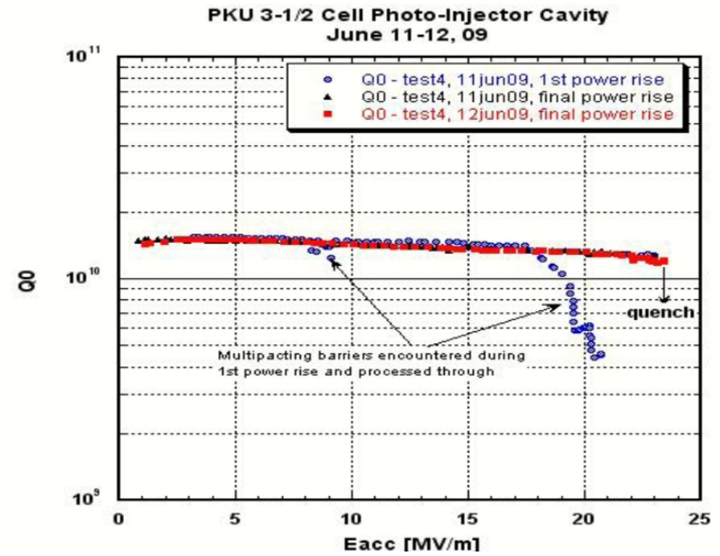


- 90 KV Pierce DC gun with Cs_2Te cathode matched with SRF cavity
- Providing 3-5 MeV electron beam with bunch charge up to 60 pC and low emmittance

DC-SRF Photoinjector

- Design and manufacture started in 2007 and 2008
- 3.5-cell large grain cavity has been used

  Vertical test at Jlab: 23.5 MV/m @ Q_0 >1E10
- Assembling and connected to 2K cryogenic system in 2010
- RF test experiments and preliminary beam test in 2011
- Upgrade of RF power supply, beam line since 2012
- Upgrade of drive laser since 2013
- Stable electron beam in 2014

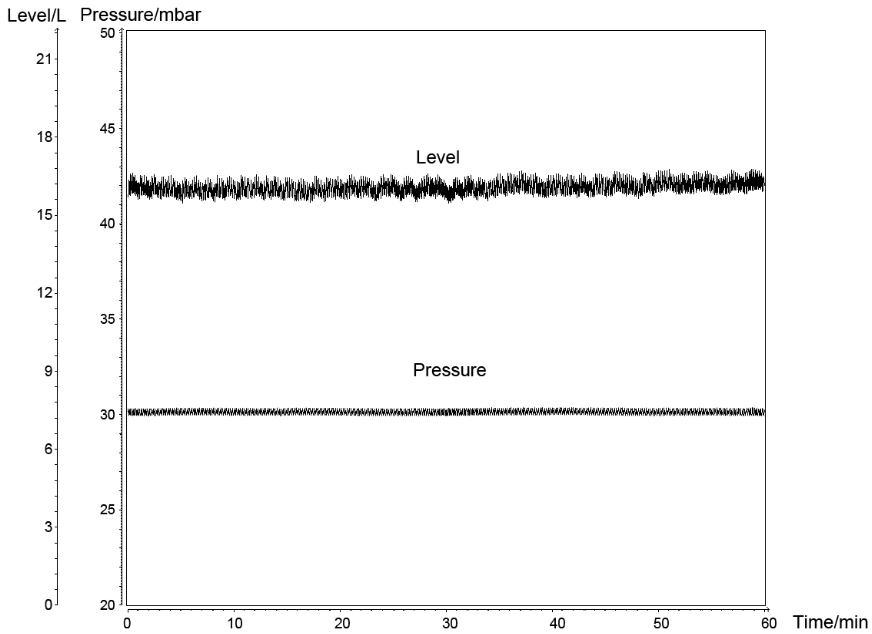


Closed Loop 2K Cryogenic System

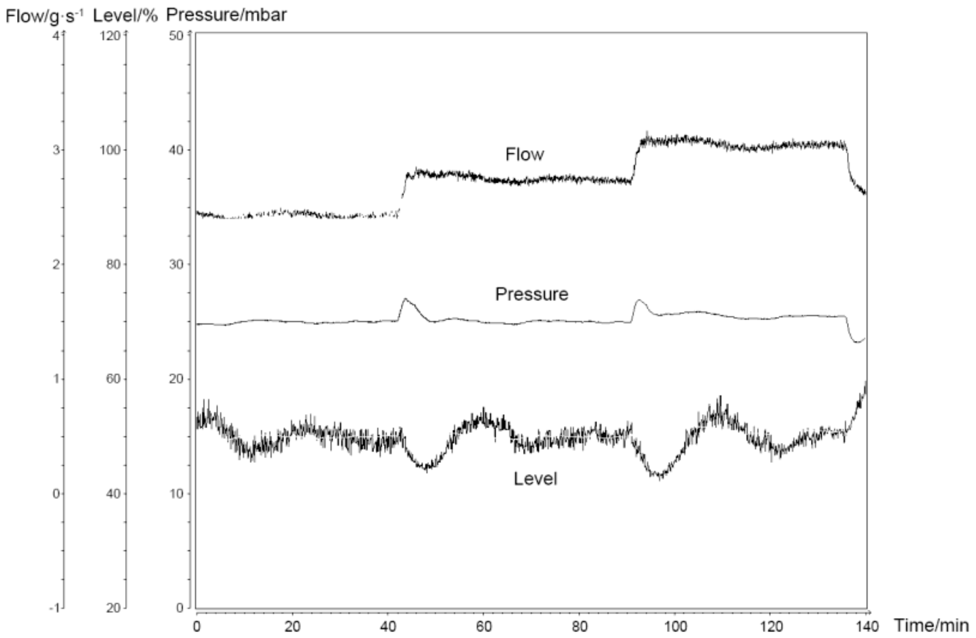
- Main parts from Linde, transfer lines made in China
- Total cooling capacity: more than 65 W at 2.0 K

Operation of Cryogenic System with Cryomodule

stability

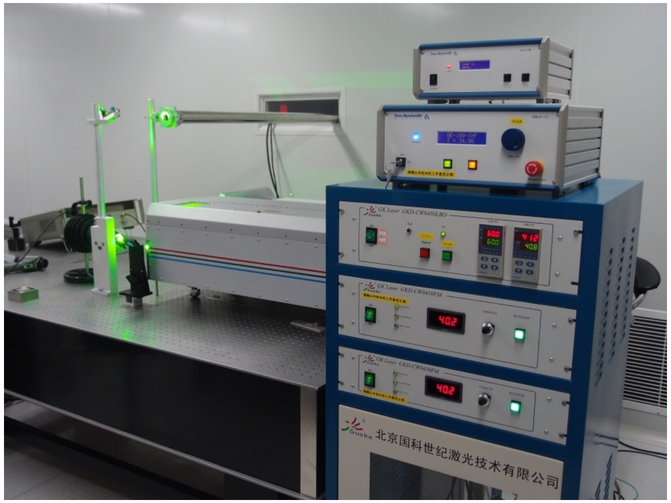


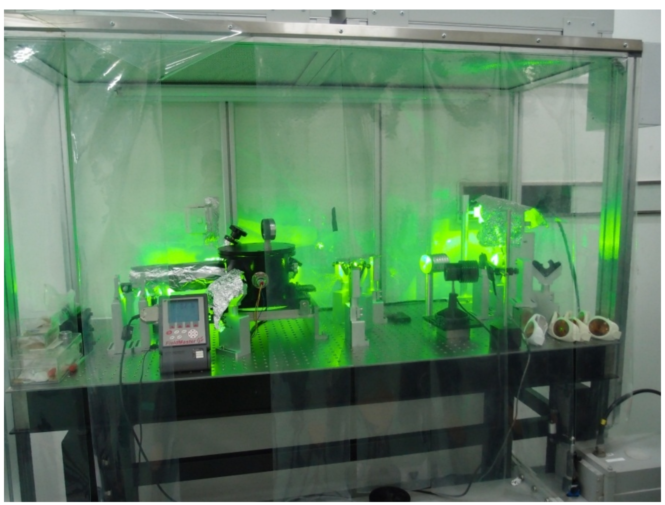
recovery after heat load changes



- Successive approximation method: the high and low limits of the control valves were preset and finely adjusted to avoid large fluctuation of the helium pressure and level.
- The instability of the helium pressure can be controlled **within ±0.1 mbar** and the helium level is **within ±5%**.
- Heat load change due to the adjustment of cavity gradient and the duty factor of RF power.
- 2K cryogenic system could be recovered from the pressure instability and helium level instability within short time.

Drive Laser Upgrade





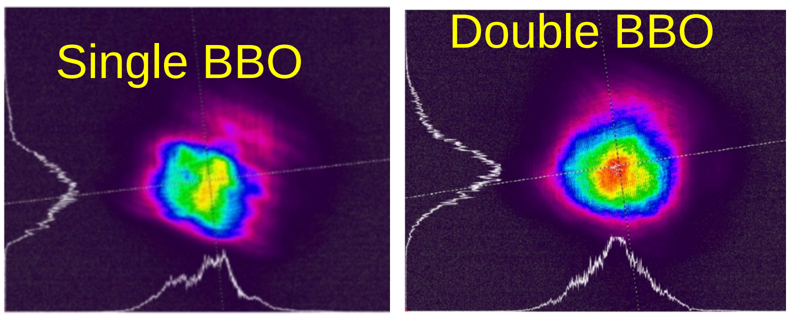
Before upgrade

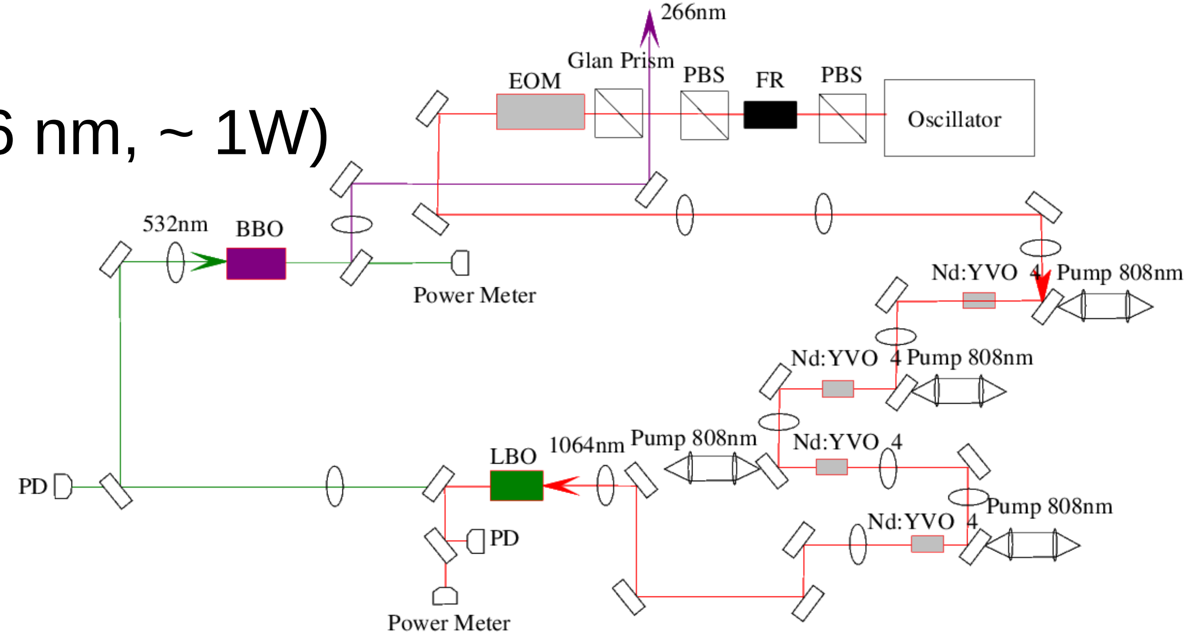
After upgrade

Seed: Timebandwidth GE-100 XHP, 81.25 MHz, 5W at 1064nm

Drive Laser Upgrade

MOPA (1064 nm, > 40 W)
SHG (532 nm, 10 W)
FHG using double BBO (266 nm, ~ 1W)



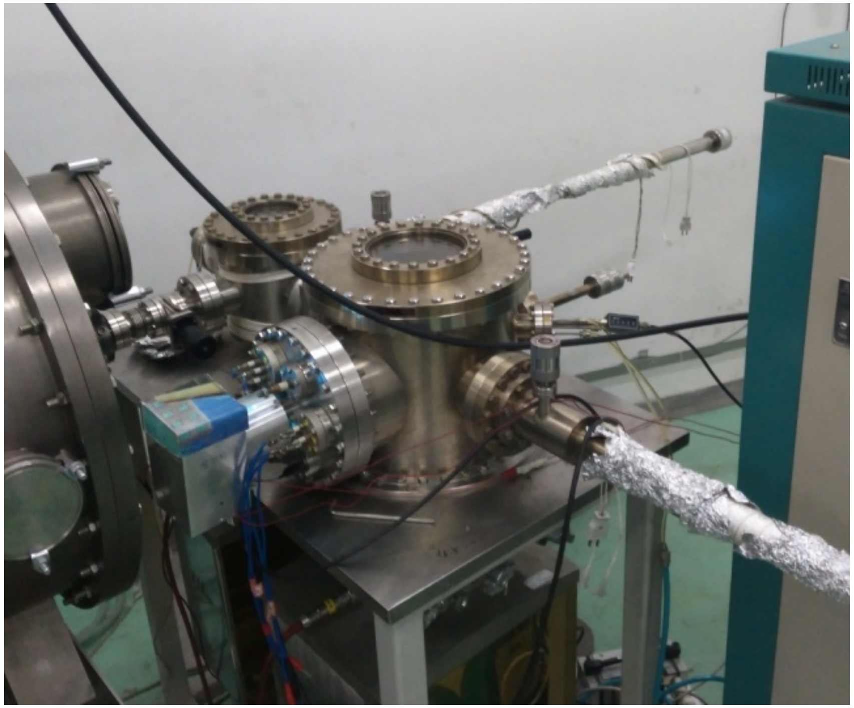


- Long terms UV power instability <5%
- EO used for repetition rate adjustment, from 81.25 MHz down to 0.1625 MHz; mechanical shutter used for macro pulse manipulation
- Commissioning / beam profile measurements at 0.1625 MHz while keeping the laser pulse energy (at 266 nm) unchanged

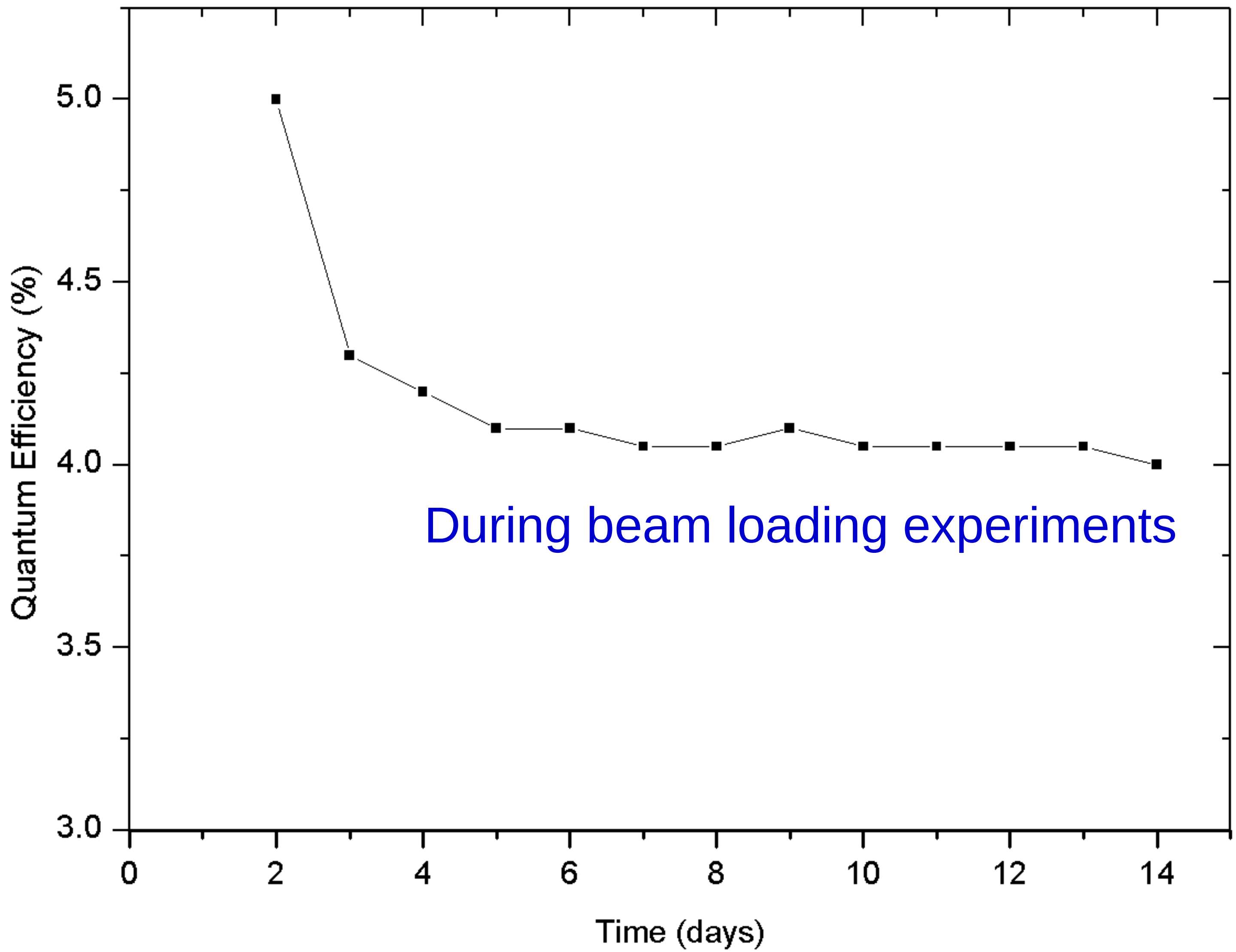
Improvement of Photocathode Preparation

- Vacuum in deposition chamber has been improved to ~1E-7 Pa with a bigger sputtering ion pump (600L/s);
- A SAES NEG pump (400L/s) has been equipped;
- The stainless steel plug polished mechanically, rinsed in ethanol and acetone ultrasonically, and heated at 120-150 degree for more than 10 hours.

► On-line Cs_2Te photocathode preparation system



Long-term Behavior of Cs_2Te Cathode

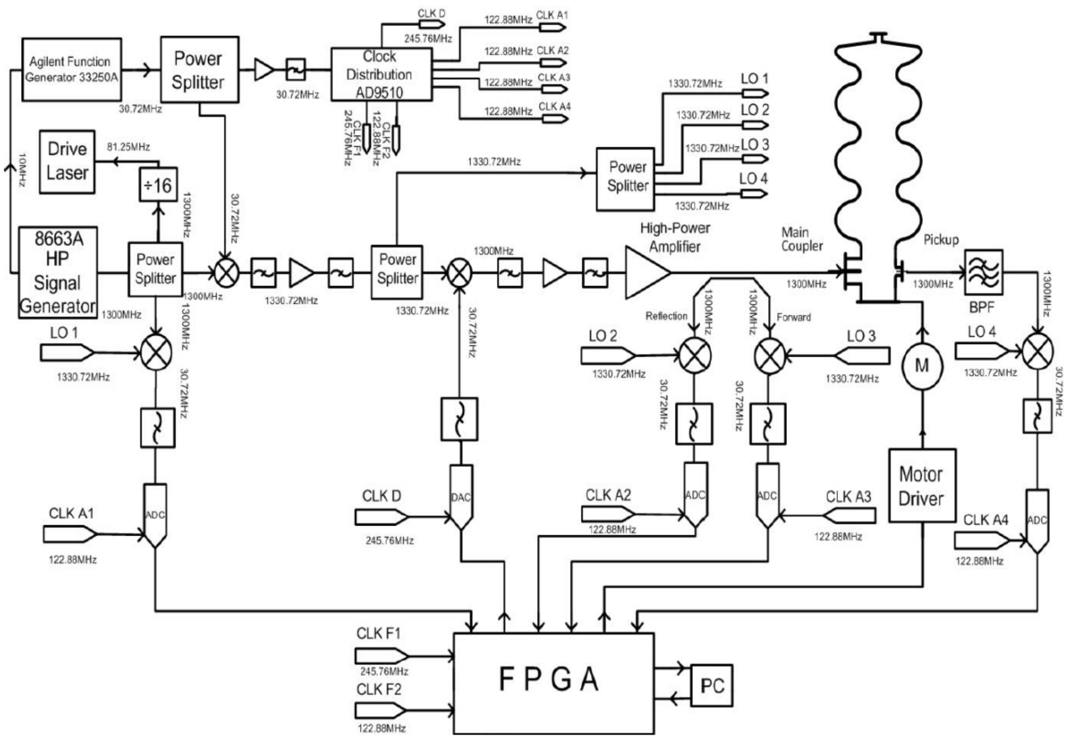


1.3 GHz 20 kW Solid-State RF Power Amplifier

- Can work in both pulse mode and CW mode.
- Output RF power can achieve 20 kW with matched load, and 16 kW with total reflection.
- 3 dB bandwidth is more than 30 MHz.

(F. Wang's Talk on Wednesday afternoon)

LLRF Control System Improvements



Digital Low Level Radio Frequency (LLRF) control:

- Two feedback control loops for amplitude control and phase control.
- PI controller in FPGA adjust output signal to compensate the deviation

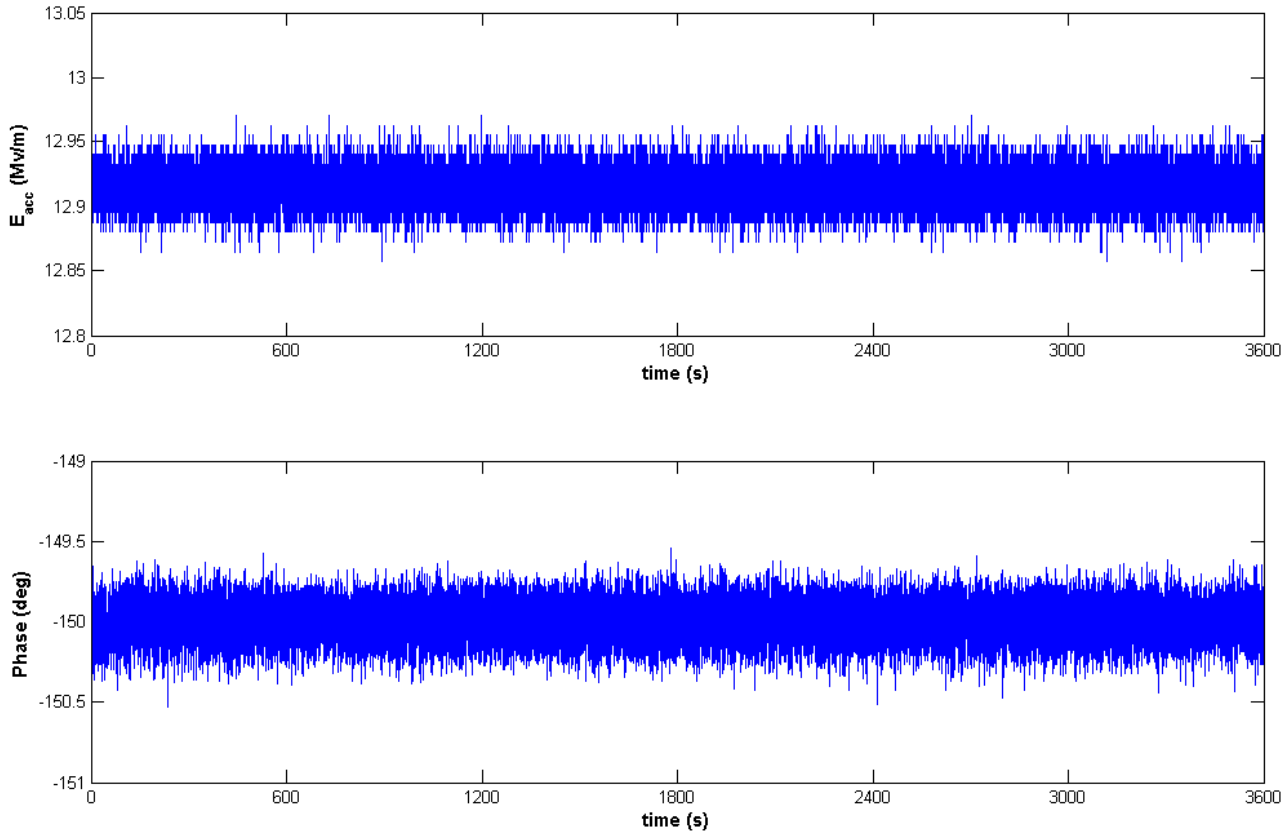
- A DC offset block was added in the FPGA to compensate the DC offset observed in the tests.
- For pulse operation, gate signal was added to the feedback path and the control algorithm was modified to handle lorentz detuning.
- A hardware UDP core was implemented for high speed signal monitoring.
- new control UI offers run-time plotting/modifying for many internal parameters.

LLRF control instability of the amplitude and phase: 0.1% and 0.1° (rms)

Acceleration Gradient (E_{acc})

E_{acc} in different conditions have been investigated

- E_{acc} was increased up to 17.5MV/m in pulsed mode with a duty factor of 10% and a repetition rate of 10 Hz.
- E_{acc} reached 14.5MV/m for CW mode



◄ Amplitude (up) and phase (below) signals of 3.5-cell DC-SRF injector at 12.9MV/m without beam load.

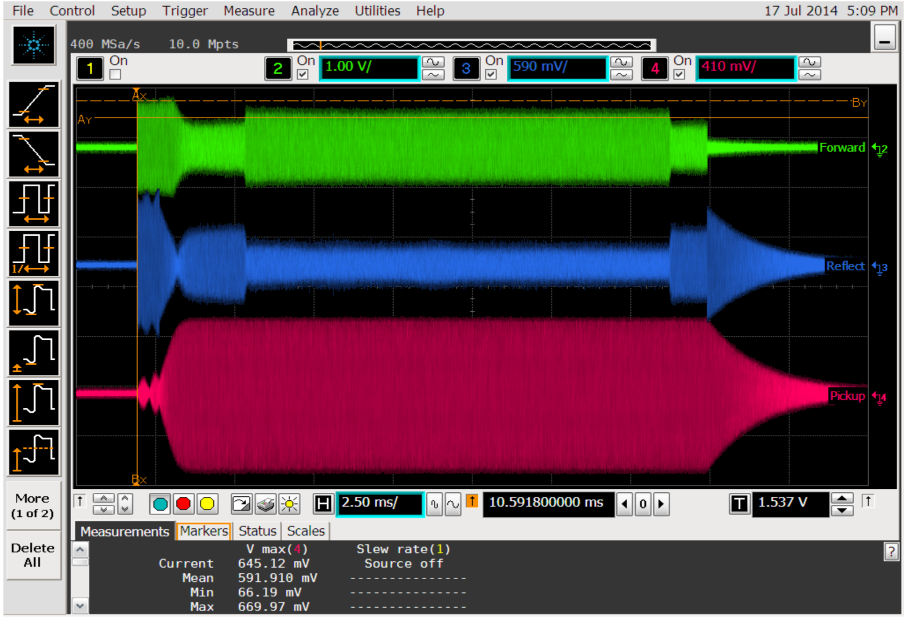
Upgraded Beam Line

Beam Load Experiments

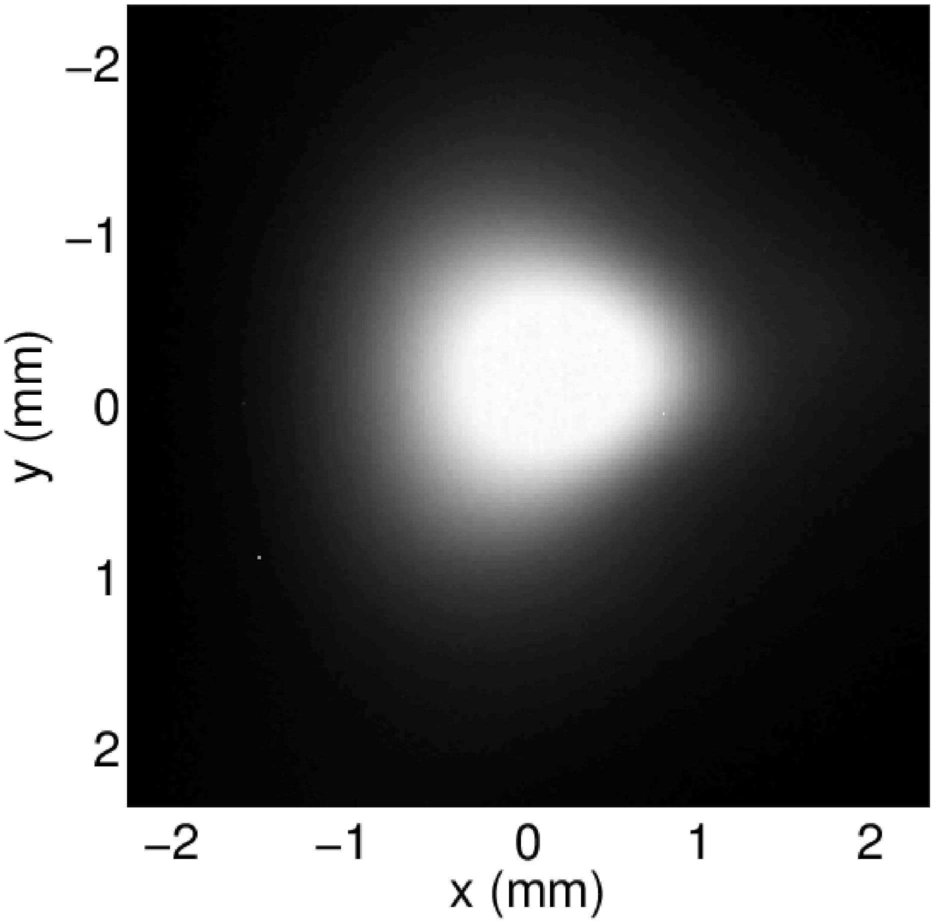
- Beam commissioning at a low beam current, reducing the duty factor of laser rather than reducing laser power to keep the same bunch charge for different average current.
- After commissioning, the duty factor is gradually increased for high average current operation. Degassing of the dump faraday cup became serious with higher beam current.
- To reduce the risk, the DC-SRF photoinjector is operated in pulse mode.

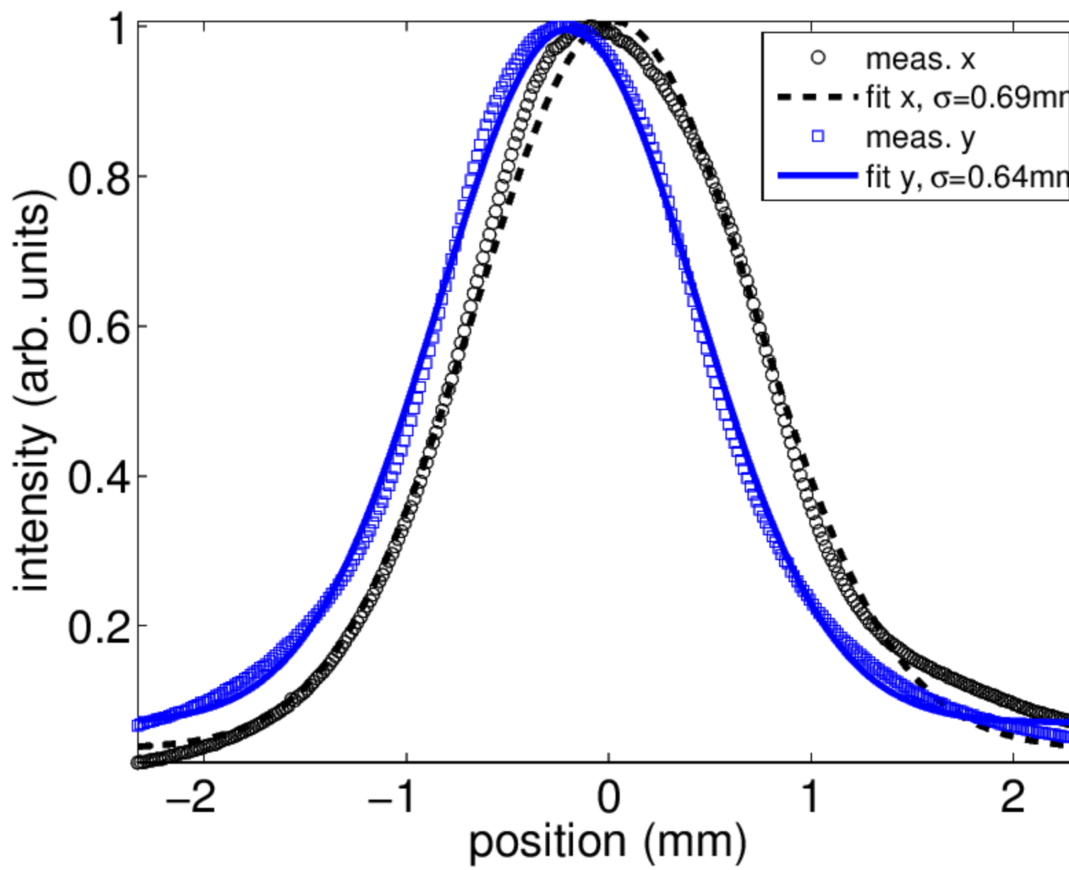
▶ Forward, Reflected and pickup RF signals with pulsed beam load

- **Electron beam energy 3.4MeV**
- **Duty factor 7%, avg. current 0.55mA**

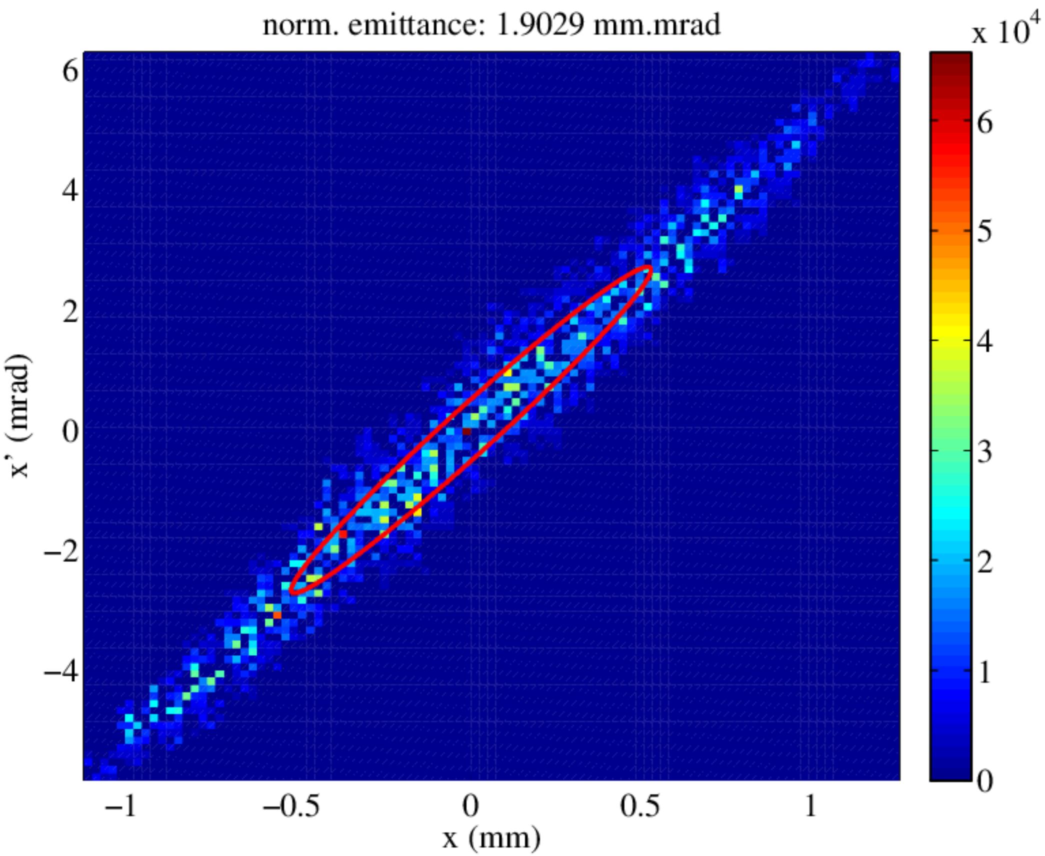


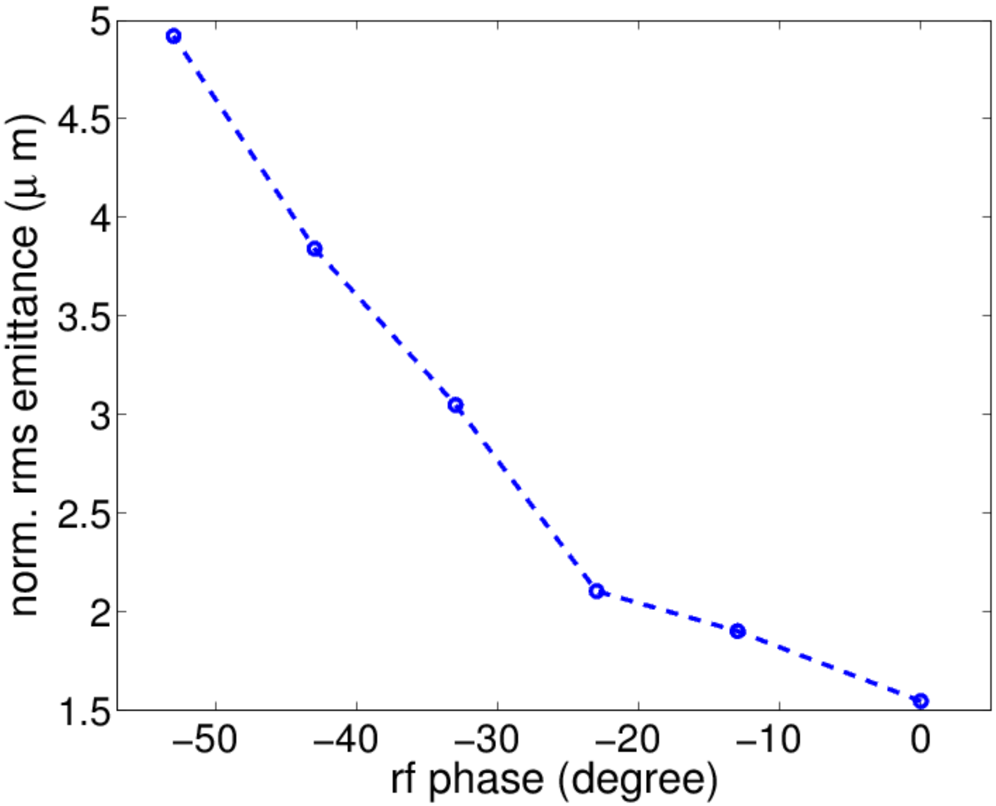
Transverse Electron Beam Profile





Emittance Measurement

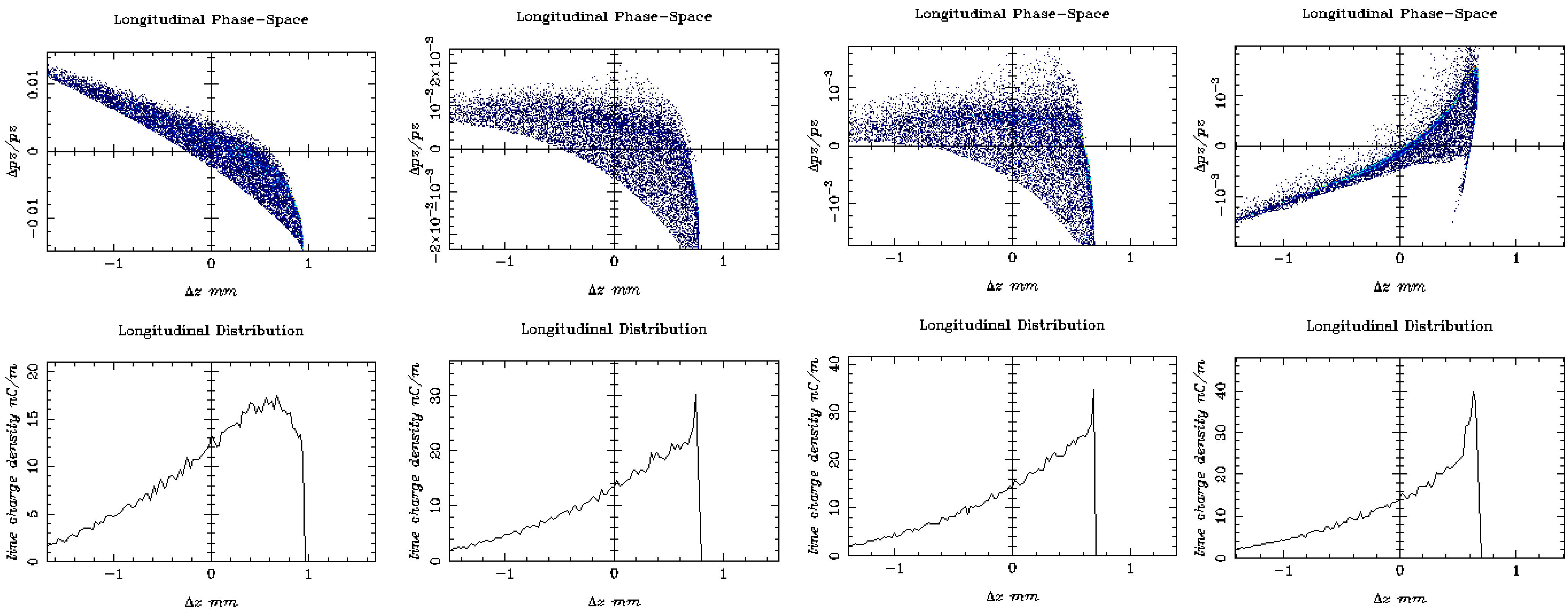




- Single-slit scanning method was used to measure the emittance.
- Emittance was measured as a function of the rf phase.

Electron Bunch Manipulation: Velocity Bunching

(Simulation Results)



0.12 m

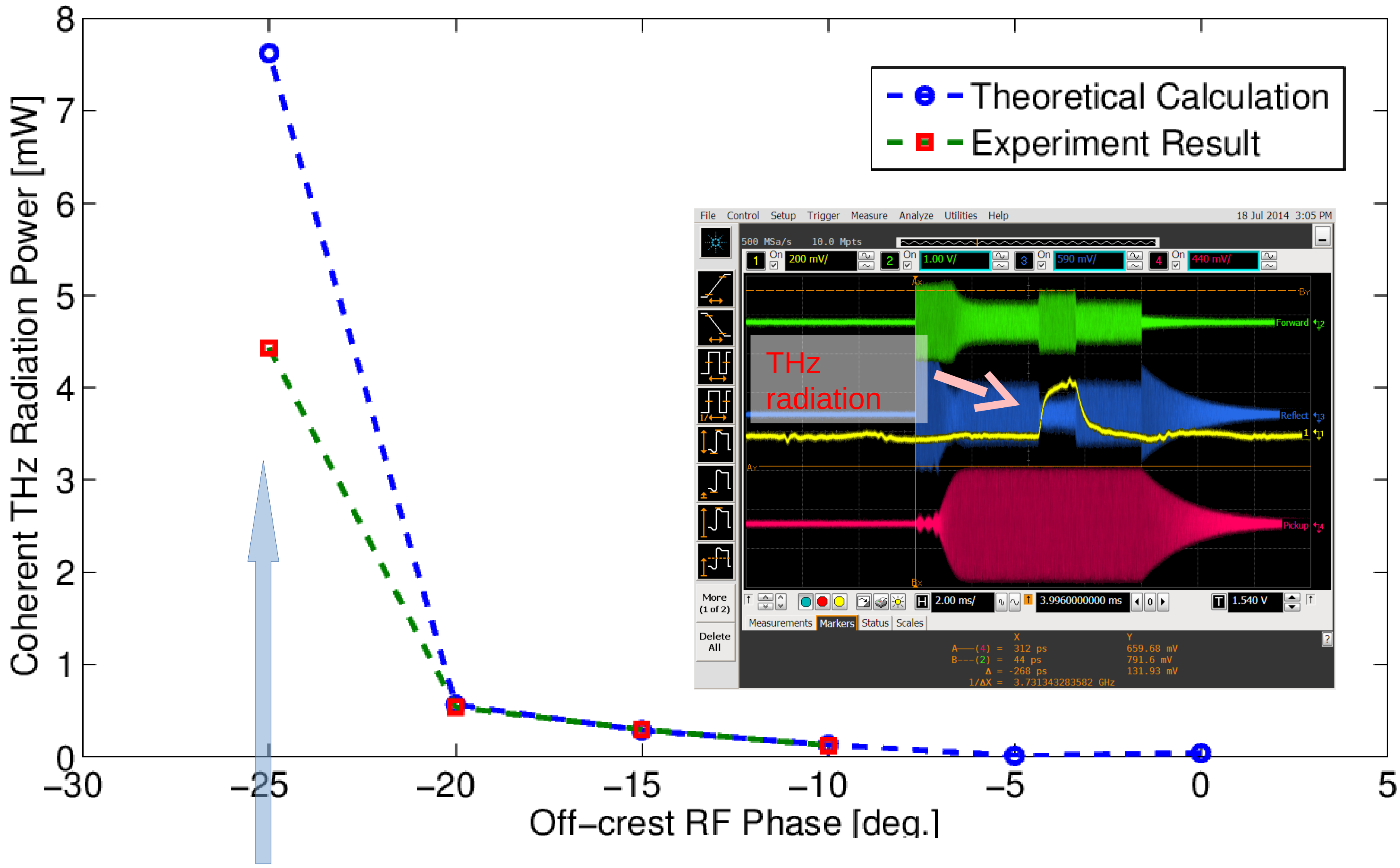
0.67 m

2.5 m

6.1 m
(Undulator entrance)

Electron beam tracking using ASTRA

1st Application: THz Superradiant Undulator Radiation



e-beam lost due to large beam size at injector exit

Operation Parameters of DC-SRF Photoinjector

Parameter	Value
Energy	2.8 - 4 MeV
Energy spread	< 0.5%
Bunch charge	5 – 50 pC
RMS bunch length	1 – 3 (5) ps
Bunch repetition rate	0.1625 – 81.25 MHz
Macro pulse length	1 ms – CW
Macro pulse repetition rate	10 Hz
Average current	0.55 mA – 2 mA
Norm. transverse emittance	2 µm

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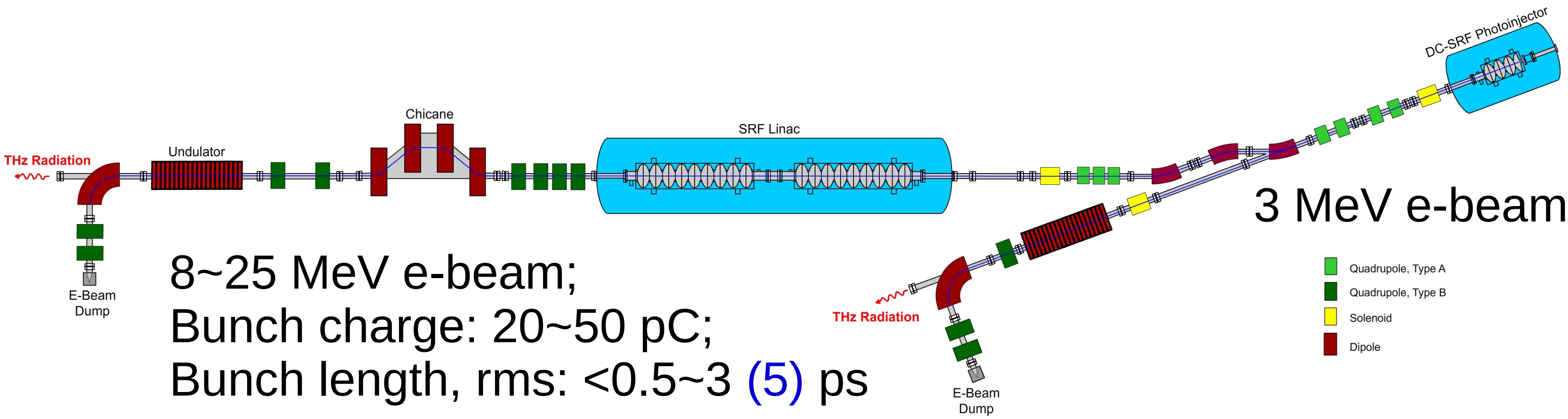
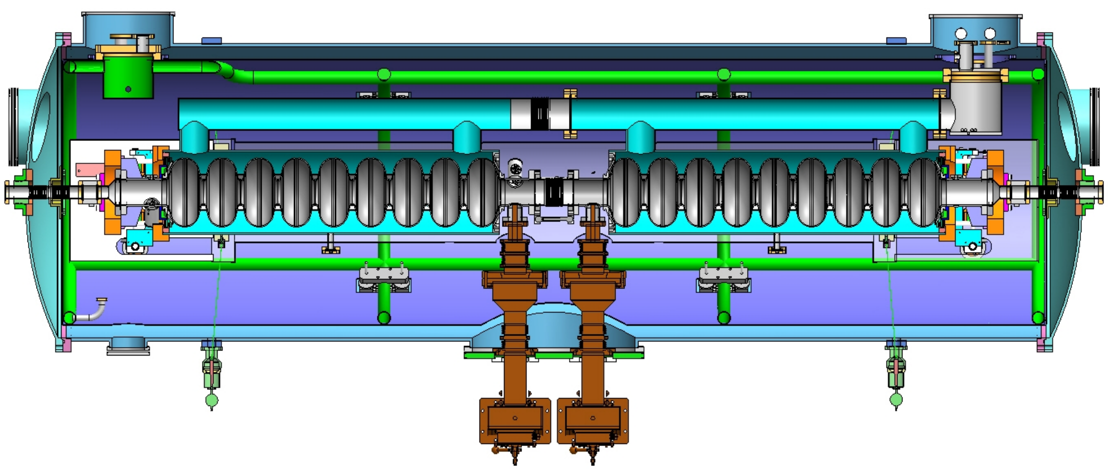
25 MeV Beam Line

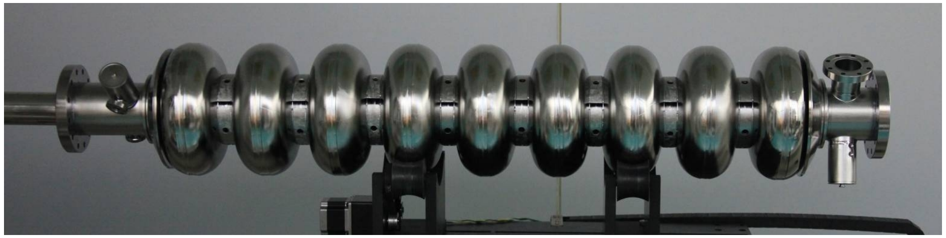


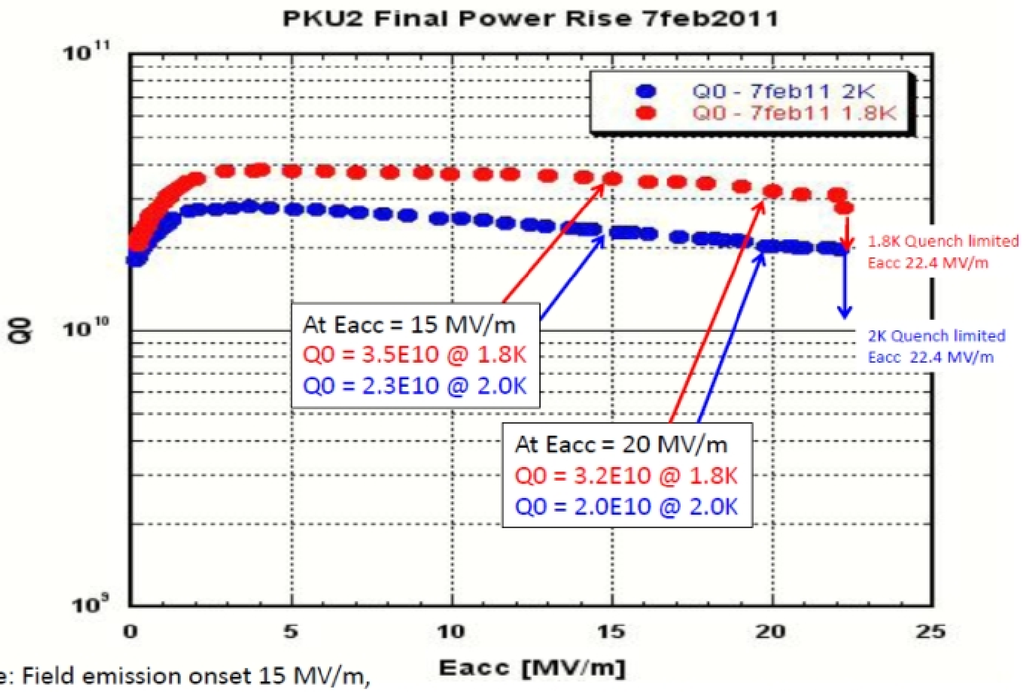
8~25 MeV e-beam;
Bunch charge: 20~50 pC;
Bunch length, rms: <0.5~3 (5) ps

▶ 2x9-cell cryomodule

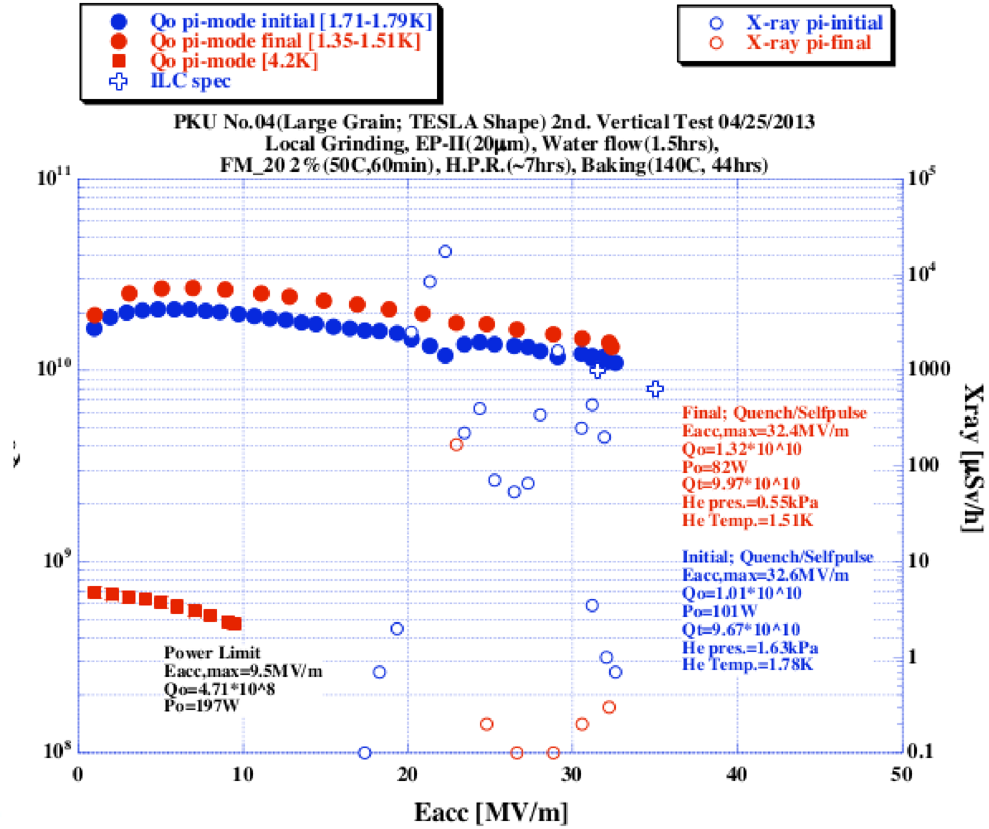


SRF Cavities of Linac





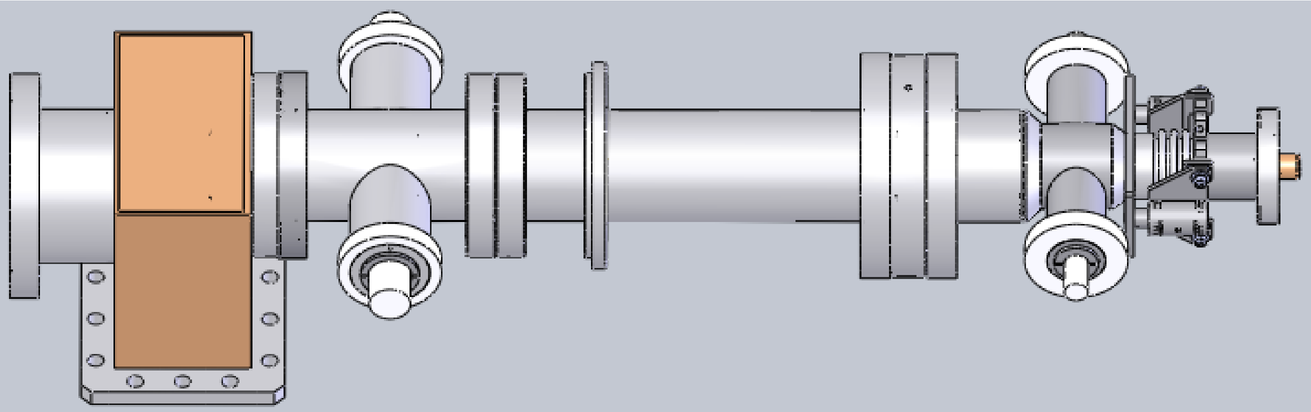
Note: Field emission onset 15 MV/m,
Maximum X-ray dose rate < 100 mR/m. No more mode mixing observed during final power rise.

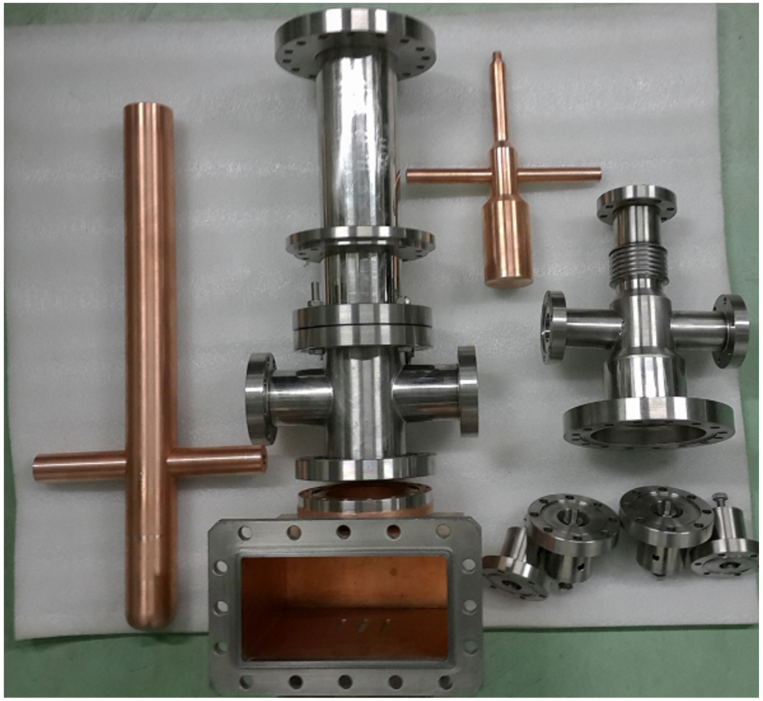


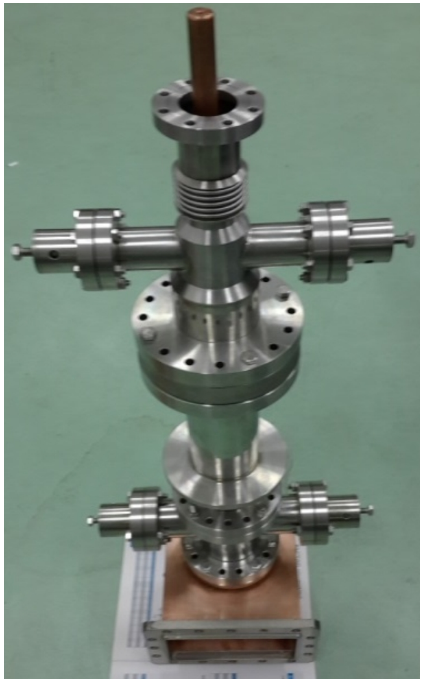
▲ **Post-processed and tested at JLab**

▲ **Post-processed and tested at KEK**

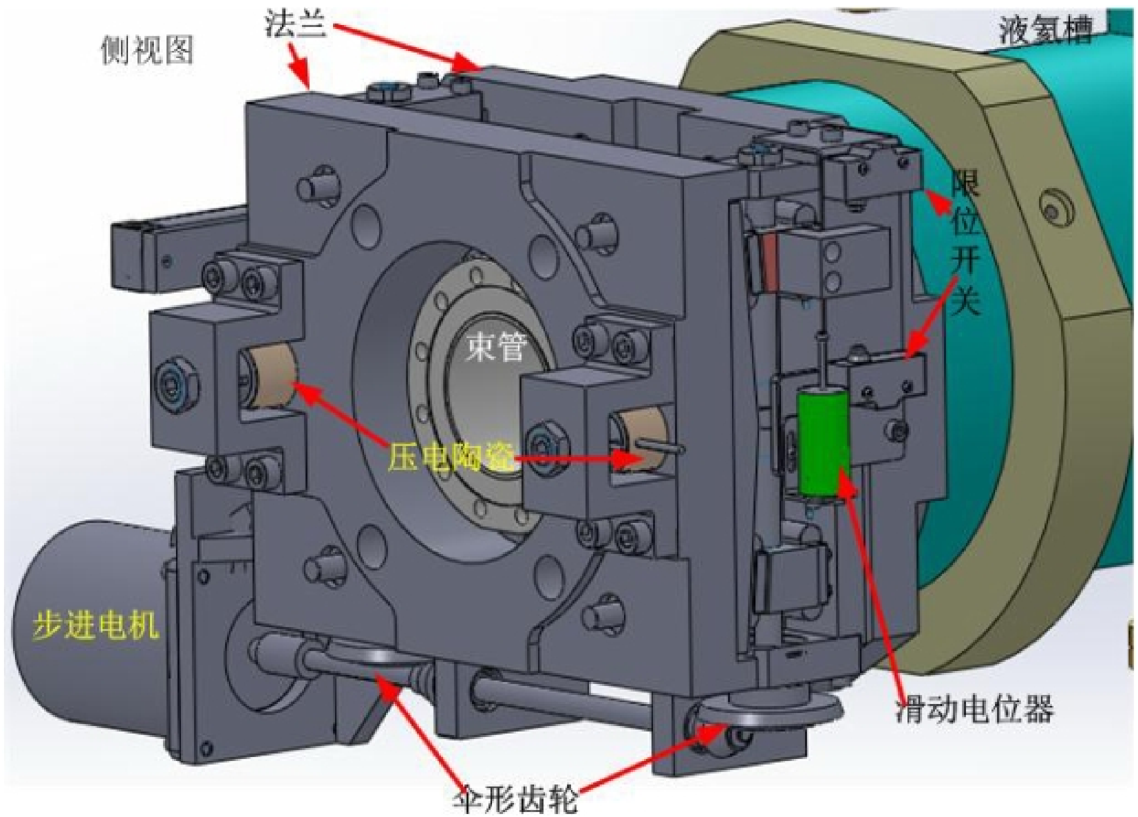
RF Coupler of Linac

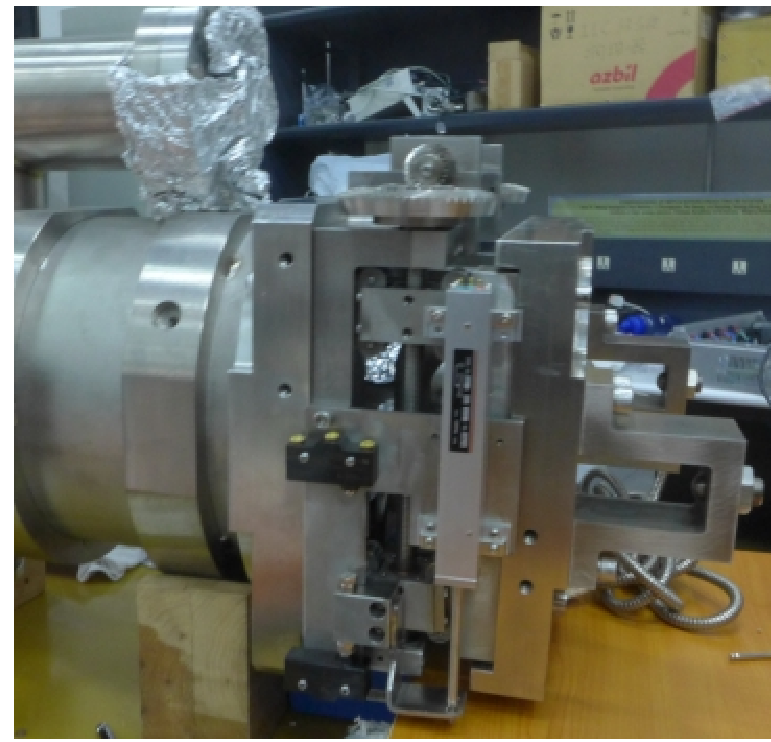






Cavity Tuner of Linac





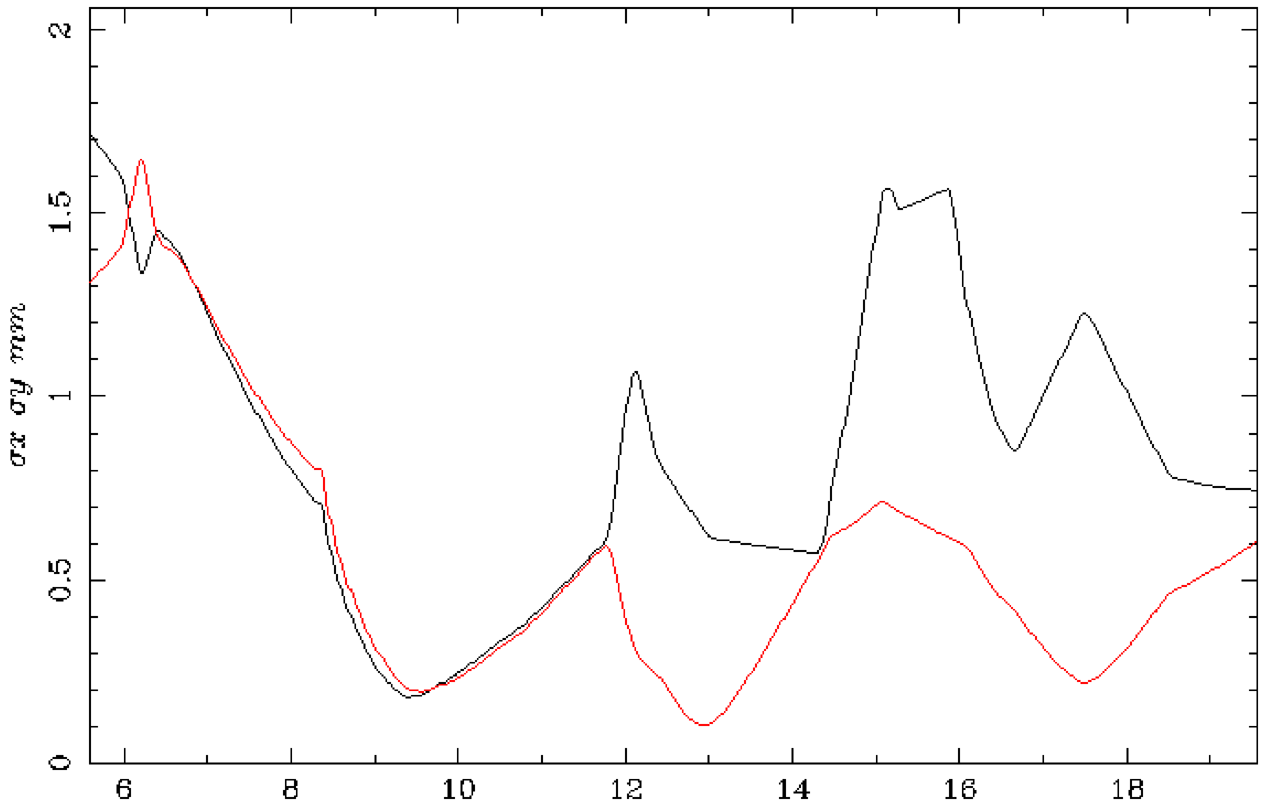
Cryomodule

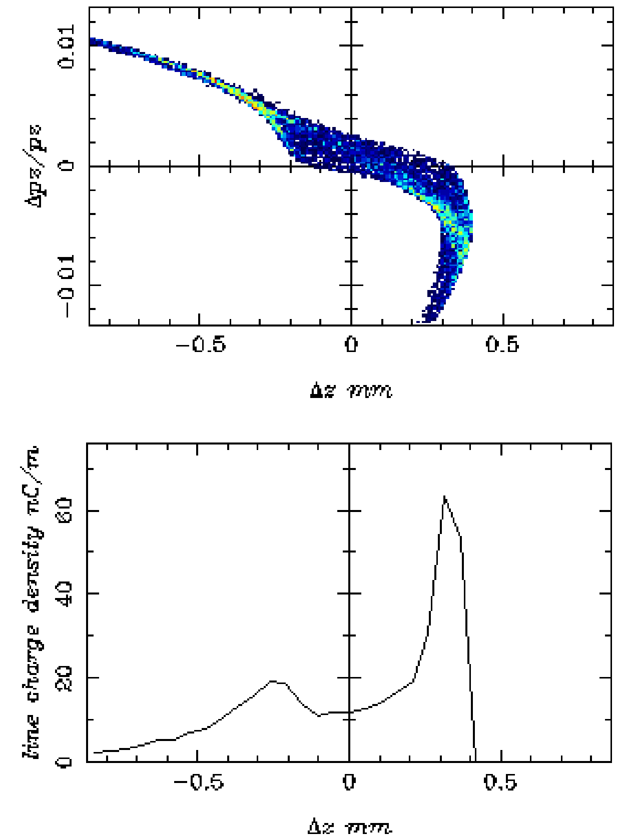
Expected This Year

- Beam load experiments at 8 - 25 MeV;
- Compressing the electron bunch using chicane.

▼ Electron bunch compression using chicane (simulation results)

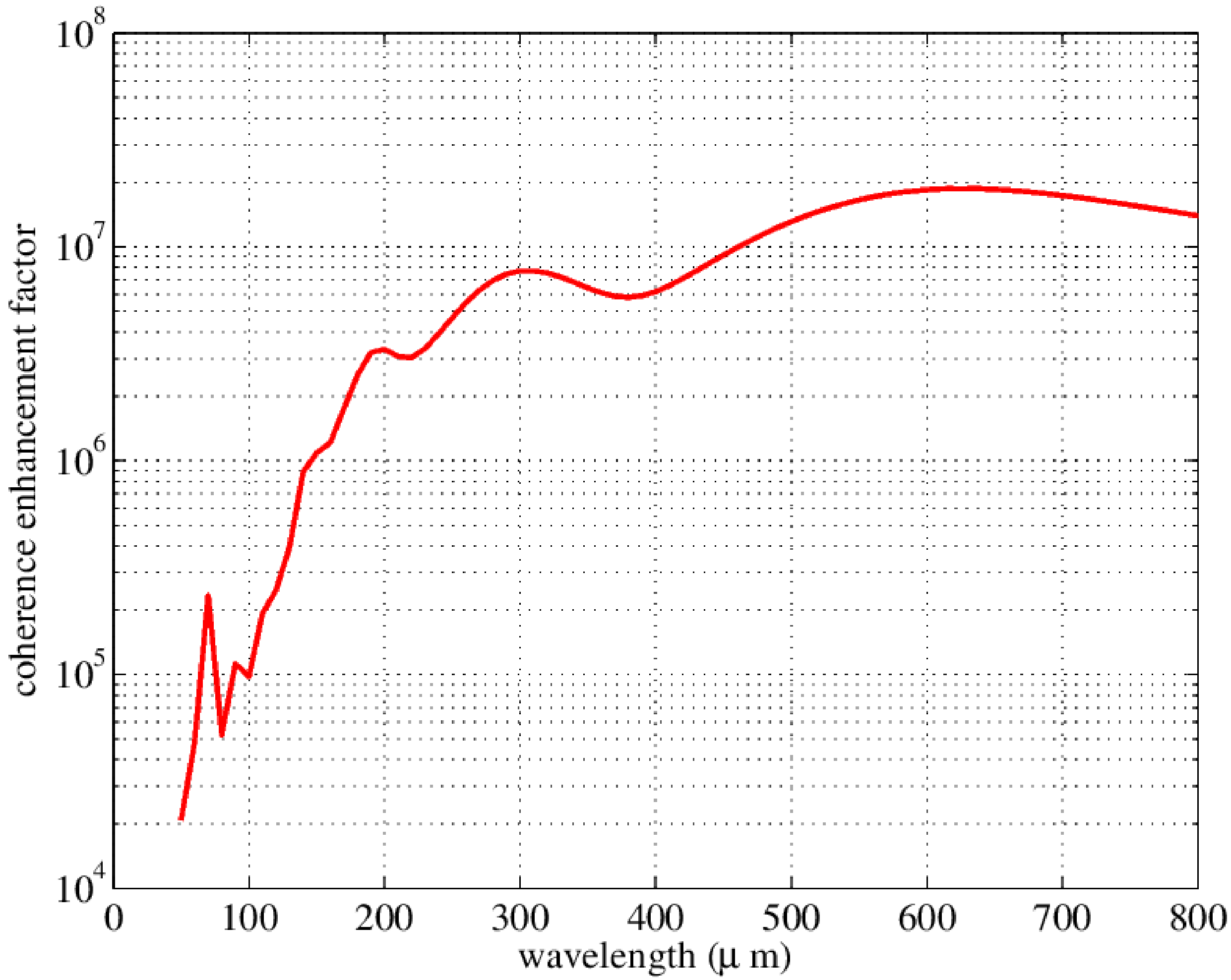
Space charge effect is rather strong, which may degrade the compression.





Expected This Year

The electron beam will first be used to generate high-repetition rate THz undulator radiation at a few Watts level.



Summary

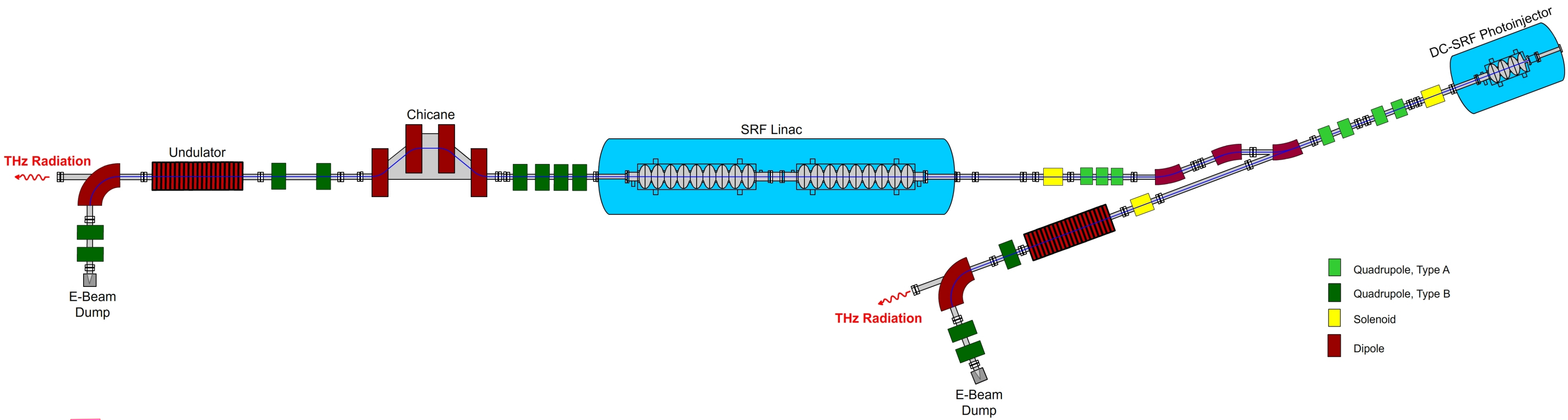
DC-SRF photoinjector

- Stable operation of DC-SRF photoinjector has been achieved since 2014.
- The electron beam has been successfully used to generate THz superrandiant undulator radiation recently.

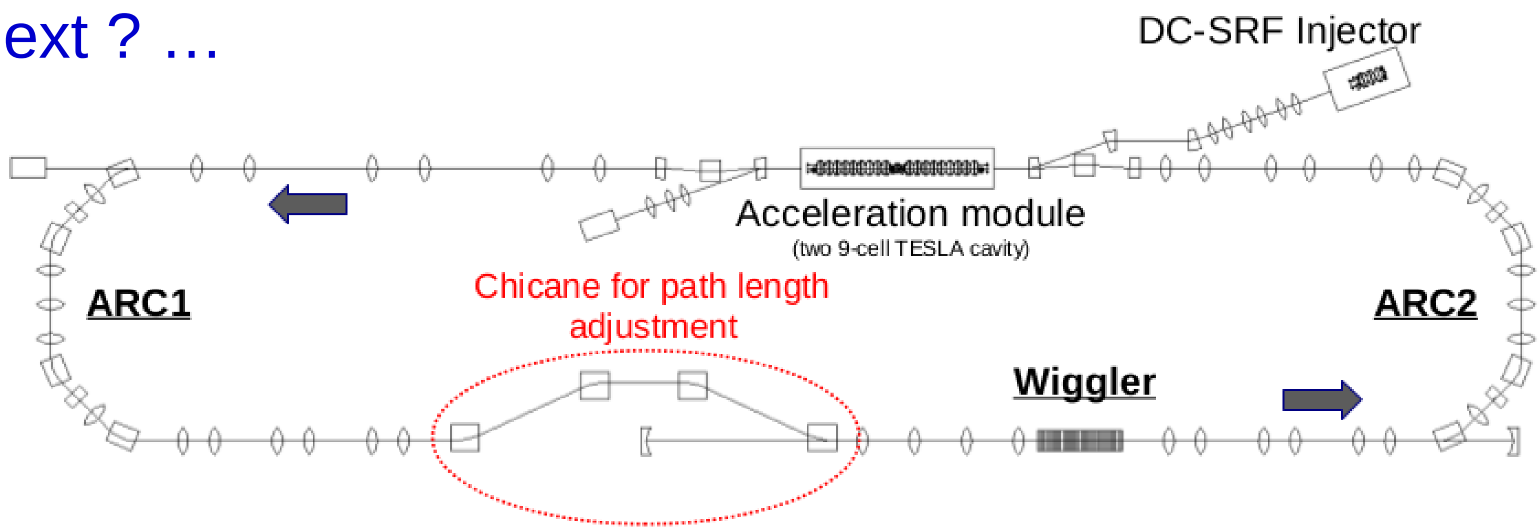
25 MeV beam line (straight section)

- Assembling of 2x9-cell cryomodule will be done before the end of this summer.
- The 25 MeV beam line is under construction.
- Beam loading experiments will be carried out this year.

Outlook



Next ? …



Thank You